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THE EFFECTS OF FLOW CONTAINING DUST ON THE RESULTS OF HYPERSONIC WIND TUNNEL EXPERIMENTS

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THE EFFECTS OF FLOW CONTAINING DUST ON THE RESULTS OF HYPERSONIC WIND TUNNEL EXPERIMENTS

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ABSTRACT. The influence of flow containing dust upon aerodynamic experiments in hypersonic wind tunnels is considered. It is found that there is an increase in drag for thin profiles, and a drag decrease for blunt profiles.

The nature and character of the influence of dust in the flow in hypersonic wind tunnels upon the results of aerodynamic experiments are considered. /187* It is shown that dust causes an increase in drag for thin profiles and, conversely, a decrease in drag and in the coefficient of longitudinal damping moment of blunt profiles.

In [1, 2] the effect of dust on the results of experiments is explained in accordance with the following simplified scheme: before impact on the model, particles have a velocity equal to the flow velocity, and they transfer their stored momentum in the form of a force impulse. However, this scheme is not always suitable. Thus, in [3] it is shown that in hypersonic wind tunnels — as a result of particles lagging behind the flow — turbulence may arise and the character of flow around the blunt profile may be distorted. In [4] and others, it is shown that during collisions of 1 - 10 km/sec or greater the force impulse may be greater than the momentum of the impacting particle. Let us look at the factors which determine the influence of dust on the results of aerodynamic experiments.

Complementary force impulse: Let us take the case of flow around a body with a flat base. Particle collision with the base leads to force impulses [4].

*Numbers in the margin indicate pagination in the original foreign text.

$$I = mW_1(1 + 0.6W_1 / W_*) \tag{1}$$

Here m is the mass of the dust particles striking the form, W_1 is the collision velocity, W_* is the collision velocity necessary to rupture the bonds of the crystal lattice or to crush finely the material of the particles (for metals $W_* \approx 2000$ m/sec [4]).

Using Newton's law of resistance, we can describe the forces acting upon the profile by particles of pure gas by the relationships

$$P_1 = \rho_2 z W_2 W_1 (1 + 0.6W_1 / W_*) F^\circ, \qquad P_2 = \rho_2 W_2^2 F^\circ \tag{2}$$

Here ρ_2, W_2, W_1 and z are the density and velocity of the gas, the particle velocity, and the mass flow level of the incoming flow dust, F° is the area of the frontal surface.

As a result of the dynamic lag of the particles, z increases in proportion to the dust level in the gas in the forechamber z_0 [5] and for $z_0 \ll 1$

$$z = z_0 W_2 / W_1 \tag{3}$$

From Equations (2) and (3) we find that in the case under consideration

$$p = P_1 / P_2 = z_0(1 + 0.6W_1 / W_*) \tag{4}$$

In flow around a sharp cone with a semi-aperture angle θ at a zero angle of attack, the drag according to Newton's law of resistance is equal to

$$P_2 = \rho_2 W_2^2 F \sin^2 \theta \tag{5}$$

where F is the surface area of the cone.

As far as the force of dust acting on the cone is concerned, it is determined by the character of particle interaction with the profile. It is not difficult to show that in the four possible cases of collision [nonelastic as in Newton's scheme (Figure 1a), elastic (Figure 1b), collision with "adhesion" of the particles to the form without ejection of material from the crater formed on the form surface (Figure 1c), and collision with "hard collisions" when the force impulse increases in accordance with Equation (1)] /188 the quantity p is described by the following equations:

$$p = z_0, \quad p = 2z_0, \quad p = \frac{z_0}{\sin^2 \theta}, \quad p = \frac{z_0}{\sin^2 \theta}\left(1 + 0.6\frac{W_1}{W_*}\right) \qquad (6)$$

A comparison of Equations (4) and (6) shows that this factor has the greatest influence in the case of thin bodies.

Distortion of flow character. In experiments with blunt forms in dusty working flows of hypersonic wind tunnels, the sharp density discontinuity under the influence of lagging particle tracks may be distorted assuming the form of a "fluid" cone, characteristic of flow around bodies with blunt ends (Figure 2). The action of this factor is rather difficult to calculate, as it requires us to know the dimensions, form, and duration of the phenomena, the frequency of occurrence of fluid cones, as well as the effects of the unsteady flow process as a result of alternating appearance and disappearance of cones. In flows around thin bodies, distortion of the flow character is observed, and thus this factor should not have any influence on the results of experiments with them.

Flow turbulence. As a result of the dynamic lag of particles, there is turbulence in the oncoming stream [3] and possibly in the boundary layer of the profile. Evaluation of the effects of dust turbulence is difficult as it can cause transition acceleration, mixing of transition points, etc. We may only expect that the influence of this factor will be slight, since in hypersonic flow friction drag is generally small in comparison with wave drag.

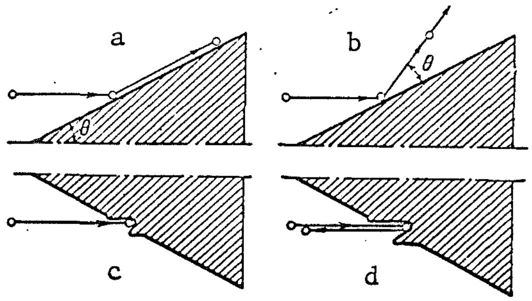

Figure 1.

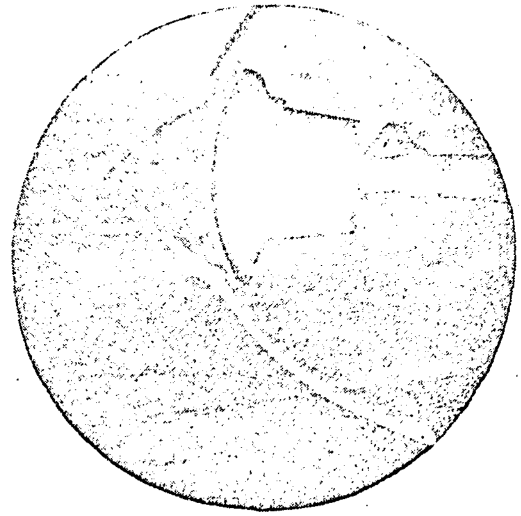

Figure 2.

Experimental studies on the effects of dust were made in a hypersonic wind tunnel with dust in the working flow by artificially increasing the amount of Al_2O_3 particles with a diameter of 5 - 7 μ in the forechamber. The parameters of the oncoming flow corresponded to M = 10 - 15 and Re $\approx 10^6$ (characteristic size: diameter at middle of form); the normal level of dust in the stream was equal to $\approx$0.05%.

We studied the coefficient of frontal drag c_τ and the coefficient of the longitudinal damping moment $m_z^{\dot{\alpha}} + m_z^{\omega_z}$. The quantity c_τ, defined as the tensor weights $m_z^{\dot{\alpha}} + m_z^{\omega_z}$, was determined by the free oscillation method [6].

The anticipated increase in frontal drag forces of the sphere due to the transfer of kinetic energy for $z_0 \approx 2\%$, according to the estimates made in accordance with Equation (4), equalled 3 - 5%. However, in actuality there was a $\approx$20% decrease in the frontal drag forces as a result of the predominant influence of fluid cones, the number of which in these experiments was as a rule one order of magnitude greater than usual. Still more significant (also due to the distortion of the discontinuity form) (Figure 2) was the influence of dust on the damping characteristics of segmentally conic bodies ($m_z^{\dot{\alpha}} + m_z^{\omega_z}$ changed by a factor of two).

Weight tests of sharp cones ($\theta = 11°$) showed, as anticipated, that an additional force impulse in the flow of a dusty stream increased the measured value of the frontal drag coefficient of the cone. Below we give the values of p thus found compared with the calculations (above — angle of attack $\alpha = 0$; below — angle of attack $\alpha = 10°$).

Equation (6)

Experiments	(Figure 1a)	(Figure 1b)	(Figure 1c)	(Figure 1d)
0.15	0.008	0.016	0.22	0.33
0.03	0.008	0.016	0.063	0.1

It is clear that the best correspondence is found in calculations from Figure 1c. /189

Study of the damping coefficient of the longitudinal moment of a sharp cone at a dust level of $z_0 \approx 0.3\%$ showed no differences (within the limits of measurement error) between normal experiments ($z_0 \approx 0.05\%$) and the calculated data.

In the experiments carried out, the influence of dust flow turbulence on aerodynamic characteristics was not observed, since this factor (when it could have an influence) was evidently accompanied by the greater influence of other factors.

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